Fermi National Accelerator Laboratory

TM-1561

The Design, Fabrication, Operation and Maintenance of (41) 400 H.P. - 600 SCFM Helium Screw Compressor Systems (Five-Year Operation Report)

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December 1988

Operated by Universities Research Association, Inc., under contract with the United States Department of Energy

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INTRODUCTION

Fermi National Accelerator Laboratory(Fermilab) uses thirty-four (34) identical compressor systems connected to a common header to supply clean high pressure helium gas feeding 26 refrigeraors supplying liquid helium to 777 super conducting magnets. There are seven (7) similar compressor packages in other locations. The purpose of this paper is (after five years of operation) to present all the problems, modifications and experiences associated with the design and operation of these compressor systems.

Maintenance Staff

One supervisor, six technicians perform ALL the work required to inspect, service, remove, overhaul, and reinstall any part of the 34 compressors systems that operate in seven(7) separate buildings.

Typical Skid Package

The typical compressor package consist of a two stage Mycom compound screw compressor, type 2016 C, mounted on a rigid structural steel skid. The driver is a 400 H.P., 3600 R.P.M. horizontal induction motor with a soft starter.

The package includes the compressor, motor, oil separator/reservoir, oil pump, oil cooler, after cooler, with all required instrumentation and controls.

Following the aftercooler is a purification system consisting of three stages of coalescers for oil mist removal, charcoal bed for oil vapor removal, molecular sieve bed for water removal, and a final filter to prevent particulates from entering the high pressure helium gas header.

The system is designed to provide clean dry helium gas at 285 PSIG to a 4-1/2 mile header supplying 26 satellite helium refrigerators located around the Tevatron Accelerator.

LIST OF COMPONENTS

1. COMPRESSOR BODY
2. MOTOR
3. OIL
4. OIL PUMP
5. OIL FILTERS
6. OIL COALESCERS
7. HEAT EXCHANGER
8. CHARCOAL BED
9. MOLECULAR SIEVE BED
10. FITTINGS, GASKETS AND SEALS
11. COMPRESSOR SHUT DOWN INSTRUMENTATION

1. Compressor Assembly

The first stage is coupled to the second stage screw with a gear type coupling. Matching screws are freely driven. High pressure oil seals and lubricates the screws. The clearances are .002 inches between rotors and .007 inches rotor to housing. Babbitt bearings support the rotors, ball type bearing bear the thrust loads. Rotors are the heart of the machine which are very expensive fine machined parts.

The screws are made from heat resistant cast iron, a material that difficult to repair. The journals, if damaged, may be ground, chromeplated and reground. Drive ends and key ways may be machined and rewelded (see attached Appendix II).

The first stage thrust bearings have never failed. The life of this machine is determined by the second stage thrust bearings. We used to overhaul the machines at 20,000 hours, replacing only the second stage bearings. We now overhaul at 30,000 hours, replacing both thrust stage bearings. Our future overhauls, regardless of hours, will be set by our shaft end play shut down probes. The plain babbitt bearings should last over 150,000 hours.

Good results during operation, have been shown from two competitive thrust bearing companies.

A well designed suction filter screen that can take pressure in both directions is important, particularly during initial startup.

The rotor housing splits apart and is sealed with a .016 inch thick gasket, we have observed internal surface warpage and corrected it by grinding surfaces flat, within .0005 inches. Due to warpage, gaskets have blown out which caused high pressure gas to back flow to the interstage increasing horse power and decreasing thoroughput. We noticed that if the high stage is loaded and the low stage unloaded, a vacuum is pulled between the stages. This was verified by testing over ten machines with an absolute gauge. By adding a 20 percent spacer on the low stage slider, positive pressure was retained with minimal increase in horse power.

Weak areas in the packaging of our skid are the second stage, which cannot be removed without removing the entire compressor. Motor and compressor mounting pads were welded, but without a final machining, this has more than doubled our shaft alignment time.

There are pockets at the base of the skid where oil and water can accumulate, making clean-up difficult.

The slider hydraulic valves are a high-maintenance item because stop washers within these valves shatter. The slider cylinder travel adjusting valves should be needle valves. Appendix I covers compressor overhauls.

2. Motor
400 H.P./3600 R.P.M. Horizontal Induction Motors

During initial start up, many motors were destroyed by operators in the Control Room (the compressor systems are many miles from the Control Room). Motors are started, stopped and monitored from the Control Room. Re-start time delays were set to near zero and multiple starts burned out many of the motor fields.

A good practice to use during operation is to allow only two(2) consecutive cold starts or one re-start, then wait for at least 45 minutes to allow the motor to cool down. All high power lead connections should be mechanically checked once a year and routinely checked for high temperature.

The motors are lubricated, and vibration analyzed every six months. Motor couplings have been balanced. Whenever coupling are removed, the motor shaft was checked for vertical ball bearing play. A new motor bearing has a .002 to .004 inch play.

On one occasion, we witnessed an unbalanced voltage to the motor windings and before the motor could be stopped, it shorted out. What startled us was the vibration of the floor and building due to the unstable forces. It is so important to measure the torque on the coupling bolts and use locking devices on the motor and compressor bolts.

There are so many motor repair houses that a Motor Overhaul Specification had to be written, which has maintained quality work and at fair prices. Appendix IV covers compressor overhaul specifications.

3. Compressor Oil

From Union Carbide, we purchased a synthetic oil, type LB-170X. This oil contains over 1500 parts per million of water. To reduce the water content in the oil to less than ten parts per million, we reprocessed the oil by heating to 250°F, and pulling a vacuum during the processing. Our compressor oil reservoirs contain 90 gallons with an electric immersion heater keeping the oil above 60°F.

During the first year of operation, oil samples were taken every three months on over twenty machines, checking oil for deterioration. The only significant change was the debris particle count being lower on each test, indicating that our filters were doing a good job. Union Carbide's senior chemist insisted that the oil has an infinite life. We have over 50,000 hours on some of our systems with no sign of wear.

Every one of the Technicians has had a "bath" in this oil. Every building has eye baths which have been used on occasion. No one to date has suffered any medical problems handling this oil.

4. Compressor Oil Pump
(Standard positive displacement rotor type)

Shaft seals are changed approximately every two years (16,000 hours). Shafts are spun on sleeve bearings. The manufacturer used aluminum bearings which deteriorated due to an interaction with the oil. We changed the material to bronze and after 40,000 hours of use, the bearings showed no wear.

5. Compressor Oil Filters
(ten micro full flow type)

When differential pressure across filter is greater than 20 psi, we change the filters.

On many new skids, the fabricator was very lax in cleaning pipe assemblies, oil reservoirs, etc. This resulted in having to change the filters many times. The average operational filter change is approximately 16,000 hours.

6. Coalescers

Three stages of packed glas fiber style, manufactured by Monsanto Corporation. Measured oil content from the coalescers <.1 PPM_w. Appendix V covers the operation of the coalescers.

7. Charcoal Beds

Six-hundred pounds(600 lbs.) of 4/6 mesh charcoal in 24 inch dia. x 9 foot high bed with flow upward. Many charcoal beds have been in operation for over 40,000 hours with no indication of oil carry-over. After the initial fill, the entire vessel, with charcoal, was baked with liquid nitrogen boil-off gas, heated and passed through the bed until the exit gas reached a temperature of 375°F. This took approximately 32 hours per bed. The bed is designed for 99.85% removal of oil vapor.

Appendix III covers the operation of the charcoal beds.

8. Molecular Sieve Beds

Two-hundred-eighty-two pounds(282 lbs.) of type 4 A sieve in 18 inch dia x 6 foot long bed with downward flow.

The molecular sieve was purchased in 55 gallon drums, sealed and certified for dryness. The sieve has not been changed for over 40,000 hours of operation. The bed maintains moisture at less than 1 PPM_v.

The operation of the sieve beds is discussed in Appendix IV.

9. Heat Exchanger

Heat exchangers supplied with the skid are the standard tube and shell type with water at 80 psi, 20 G.P.M. traveling through approximately 190 tubes, having a 3/8 dia. (i.d.), oil surrounding the tubes on the shell side at 325 psi. The heat exchanger must be cleaned each year.

I would advise purchasing a total stainless steel exchanger or total copper nickel heat exchanger bundle. Mixing materials, and not welding the end of tubes, limits life. I also recommend that a helium mass spectrometer leak check be done on the heat exchanger bundle, and a full-flow removable 1/8 dia perforated metal water strainer be placed on the inlet side.

The water valves are a high maintenance problem, from the automatic sensing bulb to the scale formation build-up at the seat of the valve. It may be a good idea to use an electric actuator rotating shaft with a thermocouple type sensor. Appendix VI covers a heat exchanger specification sheet.

10. Fittings, Gaskets and Seals

Designing a helium system as one would design a high vacuum system, is the way to go, with all weld or "O" rings and 32 R.M.S. finishes. Unfortunately because of cost most standard industry components are not supplied in those conditions.

We have used epoxies on threaded joints with some success. We've also used teflon tape, but have settled for a high quality anaerobic sealant. This type has sealed with minimum cleaning and training on its application.

The gaskets are made from a teflon glass material, 1/16 thick sheet. We have made thousands of gaskets that are vacuum and high pressure tight. It is important to cover only a maximum of 30% of the raised flange, by yielding the material we establish a permanent set, one does not have to continue retighting all the bolts. Any of the standard compression fittings may be used. Polishing the ends with 300 grit sandpaper and using minimum .062 wall makes for a finer seal.

We've experienced many leaks and blown-off lines because the fabricator used thin walls, placed compression ferrels on backward, and over-tightened the fittings. Vibration has caused wear holes on many tubes. Replacing some critical lines with high pressure hoses and using vibration suppressors have reduced these incidents.

11. Compressor Shutdown Instrumentation

Our machines can shut down for any one of the following six reasons:

1. Oil Temperature too High(140^{o}F)

   This switch has tripped our machine more than any other. Lack of water, oil spills, etc.

2. Rotor Bearing Screw Probe

   The drive screw has zero movement when we position and secure our thrust bearings. When the drive screw moves more than .006 inches, the machine is tripped. A simple, valuable, inexpensive instrument preventing costly damage to the compressor.

3. Low Oil to Gas Differential (20 psi)

   The oil provides a seal around and between the rotors, lubricates the plain and thrust bearings, and removes the heat of compression. Should the oil pressure drop below the gas pressure, all these areas are affected.

4. Gas Pressure too High (340 PSIG)

   This trips only if the discharge valve is closed or an obstruction in the discharge line.

5. Gas Temperature too High (190^{o}F)

   The only time this tripped was when the high oil temperature switch failed.

6. First Coalescer High Oil Level Switch

   This has tripped a few times because our automatic oil bleed back system failed. An important switch because it extends the life of our charcoal bed.

It is important to purchase "Fail Safe Switches"; our temperature switches were NOT ALL fail safe. We have had several machines operating with high temperature switches that became inoperative. Every two years, all instruments should be checked for operation.

Appendix I

Compressor Overhaul Summary
(taken from Log Books 1 & 2)

Dave Hanabarger
(Total number of overhauls = 44)

Reason for Overhaul(disassembly)	
High Hours	17
Rotor End Play	16
High Vibrations	1
Electrical	2
Ran Hot	1
New	2
High Interstage and H.P. (blown H.S.Gasket)	4
Unknown	2
Total	44

Total compressor hours: 775, 668

Average compressure overhaul for operating machines: 18, 468 hours

Building	Compressor#	Hours	Date	Comments
FØ #1 P-1 Log #1	2021207	9,000	4/84	New High Stage(H.S.) Rotors, side, main and thrust bearings. New L.S. main bearings.
DØ #4 P-3 Log #1	2021209	9,500	8/84	High vertical vibration replaced H.S. thrust bearings, and seal assembly springs to heavier springs.
BØ #2 P-7 Log #1	2021154	21,425	8/84	High hrs. replaced H.S. thrust bearings and shaft seal pins.
BØ #3 P-11 Log #1	2021156	19,250	11/84	.025 end play on H.S. male rotor, case and rotor damaged. Rotor cleaned up in machine shop. Replaced H.S. thrust bearings.
BØ #1 P-17 Log #1	2021133	17,000	1/85	High hrs. found gear coupling twisted on shafts. Drilled off, replaced with new style. Replaced H.S. thrust bearings.
Meson P-21 Log #1	2021134	7,000	1/85	3/16 end play on H.S. male rotor Case and shaft damaged. Coupling keys twisted. Replaced all H.S. bearings and Low Stage(L.S.) thrust and mains.
BØ #4 P-25 Log #1	2021155	19,605	2/85	High hrs. Replaced H.S. thrust bearings and shaft seal pins.
AØ #1 P-29 Log #1	2021136	21,500	5/85	.009 end play shaft damage repaired in shop. Gear coupling twisted. Replaced with new type.
EØ #4 P-37 Log #1	2021215	16,400	9/85	.125 end play on H.S. male rotor. Case & shaft damaged; new H.S. thrust & main bearings.
EA #1	2021261	6,760	9/85	Ran <u>HOT!</u> H.S. Main bearings melted and seal pins sheared off. Replaced all H.S. bearings & seal pins. Female H.S. shaft touched case. Shaft repaired in shop.
AØ #4 P-41 Log #1	2021170 Coupling set screw (out). Weld repair made on shaft.	21,304	11/85	Compressor disassembled after electrical problem caused severe mechanical pounding, damaging shaft keyway areas and internal gear coupling. Shafts repaired in shop. Replaced all H.S. bearings, balance piston and gearcoupling with new style.

Building	Compressor#	Hours	Date	Comments
AØ #3 P-45 Log #1	2021169	20,000	11/85	High hrs. Replaced H.S.thrust bearings, gear coupling with new style and shaft seal carbon insert with new Mycom insert.
AØ #2 P-47 Log #1	2021171	23,086	12/85	High hrs. H.S.male thrust bearings spun on shaft. Rotor journal repaired in shop. Thrust bearings replaced.
FØ #2 P-49 Log #1	2021203 coupling set screw loose	20,700	12/85	High hrs. Replaced H.S. thrust bearings.
FØ #3 P-51 Log #1	2021219	21,250	1/86	High hrs. Replaced H.S. thrust bearings.
FØ #4 P-53 Log #1	2021202 coupling set screw loose.	20,400	1/86	High hrs. Replaced H.S. thrust bearings.
SY #1 P-55 Log #1	2021208	18,730	1/86	High hrs. Replaced male thrust bearing spacers and both (male & female) thrust bearings.
Meson * P-57 Log #1	2021216 coupling set screw loose	20,000	2/86	1/16 end play on male rotor. Both case and rotor damaged. Rotor face and journal repaired in machine shop. Replaced male H.S. thrust bearing spacers and both(M&F) thrust bearings. Replaced L.S. main bearings on F.M. side only. Reused all thrust bearings per manufacturers approval. Also suggested using locktite on set screws and raising rotors .0005/.001 in babbit bearings. Sand paper pieces were found in oil passages to H.S. bearings.
Meson P-61 Log #1	2021135	11,236	2/86	Reason for removal unknown. Found no internal problems. Replaced H.S. thrust bearings only.
BØ #1 B-65 Log #1	2021156	21,922	3/86	.034 end play on H.S. male rotor. Case and rotor both damaged. Male rotor journal repaired in machine shop. Replaced H.S. male thrust spacers and all H.S. thrust bearings.
EØ #1 P-69 Log #1	2021210	20,777	4/86	High hrs. Replaced H.S. thrust bearings only.
EØ #3 P-75 Log #1	2021213	18,449	4/86	High hrs. Replaced H.S. thrust bearings.
EØ #2 P-77 Log #1	2021214	18,635	5/86	High hrs. Replaced H.S. thrust bearings.

Building	Compressor#	Hours	Date	Comments
BØ #1* P-79 Log #1	2021257	6,000	5/86	.006 end play on H.S. male rotor. Rotor damage repaired in machine shop. Replaced both H.S. main bearings and all H.S. thrust bearings. Manufacturer suggested we open H.S. case .001/.003 to clearances of .003/.004, modified gear coupling to get .070 ring clearances. .010/.013 L.S. standard clearance.
CØ #3* P-87 Log #1	2021235 set screw loose on coupling.	17,270	9/86 damaged	Compressor motor burned out and compressor shaft gear couplings were twisted on shafts. Had to drill to remove. Replaced H.S. main bearings(without rings) and all H.S. thrust bearing. Replaced both L.S. rotors and thrust bearings. All thrust bearings used in this compressor are <u>GERMAN</u> made. Compressor equipped with Mod. 1"-12 straight threaded prox. probe.
EA #3 P-93 Log #1	2021286 coupling set screw(out)	7,458	3/87	.051 end play on H.S. male rotor. Case and shaft damaged. Replaced H.S. main & thrust bearings. Replaced L.S. thrust bearings. Modified gear coupling for .055 clearance.
FØ #1 P-97 Log #1	2021211	14,165	unknown	.010 end play on H.S. male motor. Replaced male rotors and thrust bearings. Also replaced L.S. thrust bearings.
NEW P-103 Log #1	2021296	0	5/87	Disassembled to "Mike" and measure internal components.
SY #2* P-107 Log #1	2021287 20% L.S. spacer installed.	7,064	6/87	.027 end play on male rotor. Rotor and case damaged. Rotor repaired in machine shop. H.S. main and thrust bearings replaced. H.S. disch. port modified and temp probe holes drilled in case pieces.
AØ #2* P-113 Log #1	2021169 weld repair made on shaft.	29,923	6/87	Noisy Compressor. Found bad O-ring on H.S. slide valve shaft and blown H.S. gasket. Had cases ground. Replaced H.S. thrust bearings, O-ring and gasket. Replaced L.S. rotors due to undersized journal.
DØ #2 P-117 Log #1	2021220	23,832	6/87	High hrs. High H.P. found metal chips in oil passage to H.S. bearings and under same bearings. Replaced H.S. thrust bearings and L.S. thrust bearings.

Building	Compressor#	Hours	Date	Comments
NEW P-123 Log #1	2021291	0	9/87	Disassembly to "Mike" and measure internal components.
AØ #3 P-129 Log #1	2021261	12,558	1/88	High interstage PSI. High Horse power found blown H.S. gasket. Had case pieces ground. Replaced H.S. thrust bearings and 1L.S. main bearing.
DØ #2 P-139 Log #1	2021223	29,450	2/88	High hrs. Replaced H.S & L.S. thrust bearings. Installed new plastic shaft seal insert.
CØ #2 P-147 Log #1	2021236	29,619	3/88	High hrs. Replaced high and low stage thrust bearings.
CØ #4 P-149 Log #1	2021234	28,810	4/88	High hrs. Found rolled over H.S. slider valve O-ring. Replaced H.S. and L.S. thrust bearings.
AØ #4 P-1 Log #2	2021215	13,217	4/88	High interstage & discharge temp. Found blown H.S. gasket. Replaced both H.S. & L.S. thrust bearings.
DØ #1 Pg.5 Log #2	2021222	25,750	4/88	High hrs. .007 end play on H.S. male rotor. Replaced H.S. rotors and thrust bearings. Replaced L.S. thrust bearings.
DØ #4 Pg.9 Log #2	2021207	26,976	5/88	High hrs. Replaced H.S & L.S. thrust bearings.
CØ #1 Pg.13 Log #2	2021204	28,280	2/88	High interstage, high Horsepower, and high discharge temp
AØ #3 Pg.17 Log #2	2021169 Weld repair made on both H.S. male rotor and H.S. suction case piece.	2,911	8/88	High interstage, high Horsepower and discharge temp. .040 end play on H.S. male rotor case and rotor damaged. Cracked H.S. suction case piece. Had rotor and case piece repaired in shop. Replaced H.S. thrust and main bearings, suction case piece and gear coupling. Replaced L.S. thrust bearings.
BØ #2 Pg.25 Log #2	2021209 Gear coupling set screw loose and broken. Weld repair made on L.S. drive rotor in gear coupling area.	23,729	9/88	.047 end play on H.S. male rotor case & rotor damaged. Found piece of weld slag in H.S. oil port. Rotor repaired in machine shop. Replaced H.S. thrust and main bearings. L.S. thrust and side bearings and internal gear coupling.

CØ #2 Pg.31 Log #2	2021220	3,420	9/88	High H.P. and interstage psi. Disassembly found no visual problems. Replaced H.S. and L.S. thrust bearings with German made MRC bearings.
BØ #1 Pg.35 Log #2	2021216 Shaft weld repaired in maching shop.	14,488	11/88	.064 end play on H.S. male rotor. both damaged. H.S. gasket blown out. Replaced H.S. thrust bearings. One H.S. main bearing internal gear coupling and L.S. thrust bearings.

Appendix II

Repairing Heat Resistant Cast Iron Shafts

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July 8, 1988

Fermilab is located 40 miles west of Chicago and houses our nations highest energy accelerator. The accelerator uses (34) 400 horsepower oil satuated 285 psi helium gas screw compressors, to provide liquid helium for 777 superconducting magnets in the Tevatron accelerator.

These compressors must operate around the clock; they are spaced out in buildings over a 4-1/2 mile diameter. The most expensive parts of the compressor are the screws (matched in pairs) costing many thousands of dollars. The end of the drive screw is keyed to a coupling driven by the motor. For many reasons, the surface and keyway of the drive screw at the coupling end is prone to being damaged. The manufacturer of the compressor offered new replacement parts, but no repair service.

Attempts to spray-weld the shaft failed to provide reliable adhesion, particularly in the keyway area. After consultation with many welding rod manufacturers, the following prodcedure was initiated.

1. Shaft ends were center ground to maintain shaft concentricity.
2. Machined .035 thousands from damaged shaft diameter.
3. Constructed a aluminum box with opening for shaft ends, and used brass collars to protect journals that rested on box openings.
4. Positioned shaft within box allowing repair area to protrude, then insulated outside of box.
5. Through 1-1/2 dia. hole, the shaft was heated to $375^{o}F \pm 10^{o}$, never applying heat directly on the shaft.
6. Using a Ni-rod 99, 1/8 dia. stick electrode (95% nickel, 3% iron, 1% carbon, .2% mag.), starting at the keyway with one weld-pass 1/2 the total length.
7. After the weld-pass and while still hot, the weld was peened with a hammer to stress relieve and remove the slag.

8. With each weld, the shaft was rotated 180^{o} to distribute the heat. Welding and peening with one additional pass in the keyway area was repeated.

9. After the shaft cooled to room temperature, it was machined and ground to final dimensions.

The results were most favorable. Our experienced welder was very pleased with the flow of the weld rod to the shaft. Brinell tests indicated a change of hardness from 192 to 185. The repaired area machined with no change in concentricity.

Appendix III

Extending Compressor Main Shaft Seal Life

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April 18, 1988

Fermilab, located 40 miles west of Chicago, is our nations highest energy Accelerator. The Accelerator comprised of (34) 400-horsepower, oil satuated, 285 psi helium gas screw compressors, to provide liquid helium for 777 superconducting magnets in the Tevatron accelerator.

These compressors must operate around the clock. A group of seven people maintain and completely overhaul these machines and their associated equipment. Having that many compressors of the exact same type, offers an opportunity to test different designs and materials, and attempts to optimize conditions that will contribute to long operating hours. One of the many challenging areas is the main shaft seal of the compressors, traveling at 3,600 revolutions per minute and sealing oil at over 40 psi.

The standard furnished seals are a combination of carbon as the wearing material and carbide steel as the contact surface. Leakage occurs at approximately 8,000 hours, starting with one drop per hour, and deteriorating to ten drops per minute within one month of initial observance. At this point, the seal is replaced. This takes two(2) people four(4) hours. Seal failures have been unpredictable, ranging from 4,000 to Over 26,000 hours.

The hard non-wearing surface has held up very well with minimum cost for reconditioning after removal. The wear surface is the interesting material. Different carbons have been used with the denser; more expensive types last longer. Two machines in operation are using a special bronze that leaked one drop per hour upon starting, but curiously after over 4,000 hours, there has been no change. Two machines with graphite impregnated polyimide are ready to go into service.

Important factors to be considered in extending seal-life hours are:

1. Inspect or have certification on flatness of running contact surfaces. These surfaces must be less than three(3) light bands and can be measured, using a optical flat viewed with a monochromatic light.

2. Clear and clean oil passages that provide cooling in the seal area will help eliminate failure due to overheating.

3. If O-rings are part of the shaft seal design, the O-ring surface should have a maximum 32 R.M.S. finish. This area can be polished using a 300 grit or less emery cloth.

4. After new seal installation and before reassembling coupling, test seal at operating pressure.

   NOTE: Use clean grease at seal gap. Do not use a soap solution as it may rust, damaging seal or the shaft.

5. Total run out on the shaft at the seal area should be within .0008 thousands of 1 inch.

6. The shaft coupling should be bored to the proper size and then balanced.

   NOTE; Interference fits on couplings will reduce fretting of couplings to shafts. Always torque coupling at recommended torque valves.

7. Align coupling within .002 T.I.R. elevation angularity and within .005 T.I.R. concentricity compensates for expansion difference should a motor with a aluminum housing be used.

8. Vibration readings should be taken at new installation and at seal change time. With these readings, one may be able to identify normal seal wear life from machine wear induced failure.

Appendix IV

Compressor Motor Overhaul Secifications

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July 28, 1983

This specification shall cover minimum requirements in the complete overhaul of a motor. Any motor overhaul must be equivalent or surpass original.

A. Disassembly

1. All components such as end caps, armature, bearing etc., to be disassembled so as not to damage or maul existing components.
2. Disassembled motor to be inspected and a written report shall be submitted with venders opinion as to what caused motor failure.

B. Stator Assembly

1. If stator coils are not changed, all dirt, dust, oil, etc., must be removed without damage to existing wire insulation.
2. If stator assembly is removed, no heat shall be applied. Windings are to be mechanically removed.
3. All insulation used on wire, slots, phase connections or any other part of motor must meet Class H or better standards.
4. The rebuilt stator windings shall receive a high potential test and any other tests as required by NEMA standards. Test report must be submitted.
5. Upon reassembly, minimum proper air gap must be held, recorded and submitted (less than 5% variation).

C. Rotor Core

1. Rotor Core to be mechanically sound, bearing surfaces within tolerances and surface finish.
2. Balancing of Rotor Core shall include all components of complete core assembly.

3. Balancing report to be submitted.

D. Bearings and Seals

1. All bearings and seals to be replaced.
2. All shafts and bearing bores to be inspected, measured for proper size and data submitted.
3. Bearings grease containment areas to be completely cleaned and regreased with Chevron SRI grease.

E. Final Assembly and Test

1. Motor shall be repainted with color matching existing color.
2. Motor shall be tested at full speed with vibration balance reading to be .001 mills or less in the vertical, hrizontal and axial positions. Submit all readings.

F. Warranty

1. Shall be specified with length and conditions.

G. Motor; General Information

_____H.P.
_____R.P.M.
_____Volts
_____Phase
_____Cycle
Manufacturer:
Serial Number:

Appendix V

Oil and Moisture Removal System

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The purification system removes oil mist, oil vapor, water vapor, and particulates from the compressed helium. The units are designed with consideration of modularity reliability, and necessary redundancy (i.e., guard purification).

The final configuration of the oil mist removal system is the result of a competitive bid to a performance specification. The vendor's offering was proof tested at Fermilab. High gas velocities (>100 ft/min) on the outside of the filters gave unstable performances. The final vessel design was done at Fermilab using the Monsanto "Mist Eliminator" filter and the space available on the compressor frame. Three identical stages of oil mist were installed with the first two stages removing the oil mist to levels acceptable for cryogenic refrigeration operation. The third stage then provided the above-mentioned "necessary redundancy". The first two coalescers are mounted on the compressor frame with automatic solenoid valves returning the oil to the compressor interstage. A portable skid contains a third coalescer which is used as a guard purifier. The skid also contains a charcoal and a molecular seive adsorber followed by a final particle filter.

The charcoal adsorbent vessel is installed to remove the oil vapor from the helium gas. The vessel was designed for a maximum surface felocity at .32 m/min with an upward flow. The gas velocity is conservatively low to prevent any channeling effect and fluidization of the top layer. The normal designed contact time for the gas required to traverse the depth of the activated charcoal bed is 28 sec. From a study made of the best and most economical activated carbon adsorbent, Union Carbide JXC and American Norit Sorbonorit B4, were found to be the leaders. We have purchased and installed both type of carbons. The charcoal vessel is 24" O.D. and 9 foot tall. It contains 270 Kg (~600 lbs) of carbon pellets. The carbon, as delivered from the vendor, contains ~ 2% of moisture. After the carbon is installed in the vessel, the moisture is removed by purging the bed with 500^{o}F nitrogen gas until the nitrogen coming out of the vessel (~ 375^{o}F) has a dew point of ~ -60^{o}C. The vessel is wrapped with insulating blankets. This charcoal dehydration usually takes about 1.5 days.

The molecular sieves vessel is installed downstream of the charcoal bed. Type 4A molecular sieve is used to adsorb water vapor left in the helium gas. The vessel is 18 inches in diameter and 6 feet high. The 282 lbs. of adsorbent is used to fill the vessel with conical screens on both ends. The flow in the bed is downward with conservatively low velocity. With 20% binder material and with a calculated LUB (equivalent length of unused bed) of 0.8 feet, the useable molecular sieve weight is 181 lbs. From the water adsorption isothermal curves, the 4A molecular sieve at 77^{o}F has an equilibrium loading of 8.8%. This is at 20 atm pressure and water partial pressure of 2.94 x 10^{-4} psia (1 ppm_v contamination level). This means that fresh bed (with 2% residual loading) has a capacity of retaining 12.2 lbs of water with $<$ 1 ppm_v effluent contamination.

Adsorber beds for oil vapor and water vapor removal were sized and designed at Fermilab and adsorbent performance data provided by the manufacturers. All vessels for the oil removal system have been built by outside code shops and have been designed, constructed and tested in accordance with Section VIII of the latest ASME Code for Unfired Pressure Vessels. The vessels have a U stamp for 350 psi MAWP and are protected with an ASME 350 psig safety relief valve.

The final filter is installed downstream of the adsorbent pellets material to retain any particle of 1 micron and larger. The Dollinger Corporation makes the filter assembly which consists of a 8-5/8 O.D. x 24" high vessel with a single filter element. The gas flow is from the outside to the inside of the filter. The radial fin-pleating design of the filter gives the element collapse pressure of 50 psid.

Purification System Operation & Maintenance

Oil Coalescers

The coalescer filters are permanently installed in the vessels and no maintenance is required. The Monsanto filters are built strong, and with the clean gas, they should last a long time. At some unusual compressor operation or every six months, pressure differential readings should be taken across the coalescer vessels with compressor full flow. Normal pressure differential readings are as follows:

No. 1 Coalescer	$\Delta P\#1 = 9\text{-}14$	inches of water
No. 2 Coalescer	$\Delta P\#2 = 2\text{-}4$	inches of water
No. 3 Coalescer	$\Delta P\#3 = 2\text{-}3$	inches of water

Including the adsorber skid package, the total differential pressure is 32-38 inches of water

Oil Drain

The first oil collection is just a 2 inch pipe at the bottom of a "T" fitting branch. Oil mist is separated from the gas by the inertia impaction of the oil on the side of the "T" fitting. Three solenoid valves automatically drain the oil from the pipe and the two coalescer vessels. The solenoid valves are energized by a programmable process controller to open evey 15 minutes and stay open for 30 sec. The controller is programmed to open the valves in sequence to minimize gas bypass. Pressure differential flows the oil back to the compressor's interstage pipe. Each solenoid valve has a manual bypass valve. A glass sight gage is used to visually check oil drain conditions. Normally at Drain B, from the No. 1 coalescer, the sight gage is full with oil. Opening the bypass valve, the oil should drain in less than 20 sec. Every two weeks, the drain valves should be checked for proper operation.

The coalescer No. 1 has a High Oil Level Shut-down switch to protect the oil removal system from drain malfunction. The No. 1 coalescer removes about 91% of the oil from the helium gas and 8% is removed by the 2" pipe with the remaining 1% from the No. 2 coalescer.

The following are typical oil drain data with full compressor flow (~56 g/sec:

Location	Oil Removed
Drain A (2" pipe)	200-300 ppm_w (40-60 g/hr)
Drain B No.1 Coalescer	2200-2400 ppm_w (443-484 g/hr)
Drain C No.2 Coalescer	15-40 ppm_w (3-8 g/hr)
Drain D No.3 Coalescer	<.1 ppm_w

Oil Mist Measurement

Oil contamination of 15-40 ppm_w is typically measured downstream of No.1 coalescer (valve MV-083-H). Gas sample is extracted from a small tube placed at the center of the process pipe with the opening normal to the flow. Before each reading, a purge of one minute is done to remove any previous contaminant. We use a "Balston Oil Check Kit" to measure this level of oil contamination. With this instrument, a fixed volume of gas is sprayed onto a treated slide through a controlled orifice. The exposed slide is then placed under an ultraviolet light where the size of the oil spot is compared to a similar spot on a standard slide. This method gives us a good day-to-day comparison of oil carried over after the first coalescer.

After the second coalescer, oil contamination of <.1 ppm_w is typically measured. We take this data with an "Aerosol Monitor C-20a" made by PPM Incorporated. The monitor is a microprocessor-based electro-optical instrument. The amount of contaminants in the process flow is converted into micro grams per unit volume ($\mu gs/m^3$). The helium gas passes through the center of the sensor which can be installed in line with the process piping. This instrument should only be used for aerosol contamination of <2 ppm_w to keep the optical apparatus clean from oil mist. Therefore, oil contamination should always be checked with the treated slide first. The range of the $C\text{-}20_a$ is from 0 to 0.8 ppm_w.

Adsorbent Beds

Data for oil vapor adsorption in charcoal beds is scarce. So two vessels (installed at BØ) have been built with six ports on the vertical sides to measure the MTZ (Mass Transfer Zone) wave propagation. The MTZ is the band in which adsorption is taking place. As the wave front progresses through the bed, some oil vapor begin to show in the effluent. When the wave front passes out of the bed and the effluent concentration equals the influent value, then "Saturation" capacity has been reached. At this point the carbon bed has to be changed. As a guide in sizing the vessel, Barnebey-Cheney T-430 report gives a table relating superficial contact time vs. the oil removal efficiency for compressed air application. With the designed contact time of 28 sec., oil vapor removal efficiency of 99.85% is given.

With compressor full flow (~56 g/sec), the following are the pressure drops measured across the adsorbent beds:

Charcoal bed 24" dia. vessel 4/6 Tyler mesh pellets	ΔP = 3-4 inches of water
Molecular sieve bed 18" dia. vessel 1/16" dia. pellets	ΔP = 7-8 inches of water

With the relatively low gas velocities in the beds, deterioration of the adsorbents is minimized. Data taking of the pressure drop across the vessels should be every six months.

To measure moisture contamination, we use the Panametric Model M2L, Dew Point Probes. With these sensors, -100^{o}C dew point can be measured. The type 4A molecular sieves that we use have been considered the universal product of dehydration of most fluids and gasses. Adsorption isothermal curves are available where the water partial pressure (psia) versus the adsorption capacity (lb. H_2O/lb mol. sieves) vessel with ports on the side to take dew point measurements. Molecular sieves generally behave as physical absorbents. When water molecules enter the internal sieve structure, they are held (adsorbed) by physical forces of the Van der Waals type. At some point,the adsorbents become satuated, and as the water partial pressure inside the sieve exceed the water partial pressure in the helium gas, some of the water will migrate to the gas. Every two weeks, moisture data should be taken upstream and downstream of the molecular sieves vessels. This is very important, especially during the first commissioning where we do not have any substantial data to refer to. Our goal is to have <1 ppm (<-76^{o}C at atm) of moisture effluent. Calibration check of the dew point sensors is very important for the low moisture level that we are working with. For this, we have purchased a portable field calibration system to verify the calibration of any hydrometer in use. This apparatus generates precise and repeatable concentrations of water vapor in a carrier gas stream to an accuracy of $\pm 0.5^{o}C$. When the dew point exceeds $-70^{o}C$ (2.5 ppm_v @ atm), the bed should be changed with new molecular sieves. For our goal to have <1 ppm_v of moisture, we require molecular sieves with <2% residual moisture. This is hard to achieve with standard industrial regeneration.

Final Filter

The final filter picks up the dust associated with the adsorbent beds. The filters can be changed by opening an 8 inch flange on the top of the vessel (a new gasket should be used). Pressure differential data across the vessel should be taken every time new adsorbent beds are filled and also at 6 months intervals. Typical pressure drops are 2-3 inches of water (1 micron filter size).

Appendix VI

Heat Exchanger Specification Sheet
Fermilab Spec. No. 9110-ES-130345

C.B. Pallaver
Fermi National Accelerator Laboratory
Batavia, Illinois 605110

December 1988

1. All Heat Exchangers to be reassembled with same pieces and same port positions.

2. Only new non-asbestos gaskets and new "O" rings to be used.

3. Water side of Heat Exchanger must be protected as to not damage any seal surfaces.

4. Bundle tubes and support plates must be made of copper nickel composition #C70600 (light drawn tubes) 90% copper, 10% nickel as per ATSM-B111.

5. All bundle tube assemblies must match existing heat exchangers.

6. All tubes to seal welded using Monel 187 as filler rod, after welding tubes to be swagged at each end so as to remove all support and the expansion stresses at the weld joint.

7. Outside diameter of tube bundle support plate at "O" ring end must be the same diameter as original plate with surface finish 64 R.M.S. Maximum circular grooves and 1/16 inch corner radis.

8. Tube bundle support plate at flat gasket end must be the same as original plate with 64 R.M.S. maximum finish at gasket surface and 1/16 inch corner radii.

9. Heat exchanger to be made according to ASME Boiler Code Specifications.

10. First test after assembly shall be a helium mass spectrometer test with the leak detector connected to the shell, and 50 psi helium on the water side. There shall be no detectable leak with the leak detector with a sensitivity scale maximum of 10^{-8} ats. cc per sec. helium. This helium mass spectrometer testing shall be quoted two ways:

    1) Vendor to test
    2) Fermilab to test

11. Final hydrostatic test shall be according to Code using oil supplied by Fermilab (Union Carbide LB-170) on shell side and water in tubes.

12. Fermilab to receive two (2) copies of R-1 data sheets and written certification of material and weld rod used in the fabrication of the bundle.

13. All open ports and sealing surfaces to be protected at all times. Oil and water that was used for testing must be removed and ports sealed with cover plates and gaskets before shipping.

14. Heat exchangers to be painted with high quality industrial type paint matching existing color. Do not paint over the existing name plates.